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Experimental study on 75 kW_{th} downdraft (biomass) gasifier system

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ABSTRACT

Experimental study on 75 kW_{th}, downdraft (biomass) gasifier system has been carried out to obtain temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling–cleaning train and across the system as a whole in both firing as well as non-firing mode. Some issues related to re-fabrication of damaged components/parts have been discussed in order to avoid any kind of leakage. In firing mode, the pressure drop across the porous bed, cooling–cleaning train, bed temperature profile, gas composition and gas calorific value are found to be sensitive to the gas flow rate. The rise in the bed temperature due to chemical reactions strongly influences the pressure drop through the porous gasifier bed. In non-firing mode, the extinguished gasifier bed arrangement (progressively decreasing particle size distribution) gives much higher resistance to flow as compared to a freshly charged gasifier bed (uniformly distributed particle size). The influence of ash deposition in fired-gasifier bed and tar deposition in sand filters is also examined on the pressure drop through them. The experimental data generated in this article may be useful for validation of any simulation codes for gasifiers and the pressure drop characteristics may be useful towards the coupling of a gasifier to the gas engine for motive power generation or decentralized electrification applications.

1. Introduction

The increasing cost along with fast depleting conventional energy sources with serious emissions has been a matter of serious concern worldwide. The unprecedented increase in these emissions enhances the global warming, which in turn responsible for global climate change. Under the business-as usual scenario, greenhouse gas emissions are expected to double over the next 50 years [1]. Biomass gasification is one of the several technologies with a very high potential for rural power generation applications in addition to its inherent advantage of neutral emissions of CO_2. The gasification process is a partial combustion process in which the biomass is subjected to drying, pyrolysis, oxidation and reduction reactions. In a fired gasifier, the biomass feedstock loses its moisture and then subjected to pyrolysis leading to its decomposition into char and volatiles. These pyrolytic yields react with oxygen in high temperature combustion zone where oxidation and reduction reactions yield producer gas. The efficiency of conversion depends on biomass material, particle size, gas flow rate and design of chemical reactor or gasifier. Broadly, gasifiers can be categorized based on the direction of gas flow as updraft, downdraft, cross-draft and fluidized bed. For the use of engines and turbines the downdraft configuration is suitable as it produce relatively less tar.

Research efforts are employed all over the world in order to develop efficient, low cost and reliable gasification systems and its commercialization, particularly for power generation [2–8]. Several gasifier designs are developed in past. Many of them have single air entry while others have twin entry for the inlet air. Parikh et al. [5] created swirl action in their design which allows the higher residence time of the pyrolysis gases in the oxidation zone leading to reduction in tar while particulate content are increased in the ensuing gas. The scientists at Indian Institute of Science (IISc), Bangalore, on the other hand developed an innovative design for a gasifier with twin air entry. The design featuring a unique geometry, scientifically confirmed temperature profile in combustion chamber and a novel sequence of filers [6]. Brandt et al. [7] and Bui et al. [8] demonstrated that multi-stage reactor have very low tar content due to partial oxidation of pyrolysis gas in stages.

The experimental studies on biomass gasification have been reviewed [9–15] for the present work. Kaupp et al. [10] and Dogru et al. [11] investigated the gasification potential using of rice hulls and hazelnut shells respectively. Dogru et al. [11] recommended that low pressure drop across the entire system would be the consideration in optimizing the utilization of biomass for power production engine. Zainal et al. [12] have reported studies on gasification using furniture wood and wood chips and suggested from their observations that the optimum value of equivalence

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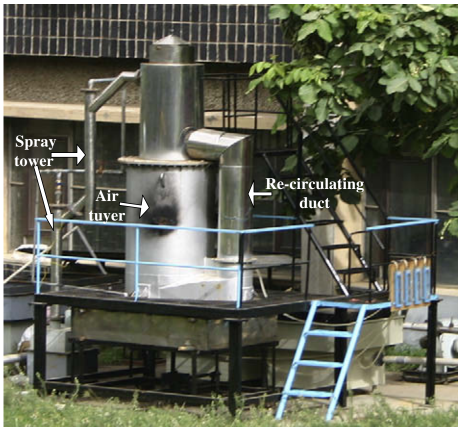

Plate 1. A view of 75 kW_{th}, downdraft (biomass) gasifier.

ratio is 0.38 for their downdraft gasifier design, while, Pinto et al. [9] have investigated the scope of plastic waste along with pine-wood gasification. They reported that the addition of polyethylene (PE) in pine-wood gasification favors the release of hydrogen, while slight decrease in carbon monoxide content has been observed in resulting gas. Henriksen et al. [13] reported the successful working and operating experiences (more than 2000 h) out of which 465 h was unattended operation continuously day and night. Yoshikawa [14] made it possible to generate relatively low level dust and tar free clean reformed gas using a small-scale gasification for wastes and biomass. Where, he has combined a fixed-bed pyrolyzer with a high temperature reformer using a high temperature steam/air mixture and demonstrated that the injection of high temperature steam/air mixture into the pyrolysis gas effectively decomposes tar and soot components in the pyrolysis gas into CO and H_2. Hanaoka et al. [15] investigated the role of main three constituents of woody biomass (i.e. cellulose, xylan, and lignin) during gasification and suggested that the fundamental information obtained in the gasification of each component could possibly be used to predict the composition of product gas generated in air–steam gasification of woody biomass.

From the exhaustive literature search, it can be observed that the good amount of experimental observations is carried out to obtain tar free gas composition (as far as possible) or calorific value, and bed temperature profile or temperature variations in various zones for different gasifying-reactor designs. The experimental data for pressure drop across the gasifier bed, cooling and cleaning units are rarely examined in detail. Since, the information of overall pressure drop may be highly crucial when the coupling is required with gas engine for motive power or electric power generation applications. Thus, in the present article, the extensive work is carried out to generate thermo-chemical/gasification characteristics of *Kiker* (Acacia) as the feedstock for 75 kW_{th} downdraft (biomass) gasifier. The elaborate trends of fluid flow characteristics of individual unit as well as system as a whole in extinguished and freshly charged mode in fired as well as non-firing gasifier; the details of experimental set-up, measuring instruments and experimental procedure have been described in details. The thermo-chemical characteristics such as gas composition, calorific value, temperature profile in terms of gas flow rate are also presented and discussed. The present article also describes the re-fabrication aspect of some failed components viz., gasifier grate, sand bed filters; the maintenance/replacement of other components viz., charcoal filter, water re-circulation line in the cooling system including pipelines in order to avoid air leakage.

2. Description of gasifier system

The pictorial view of the 75 kW_{th}, downdraft (biomass) gasifier used in the present work is given in Plate 1. In the reactor, both gas and biomass feedstock move downward as the reaction proceeds. While biomass flows due to gravity, airflow is induced through the reactor by a blower. The air used for gasification process is partly drawn from the top, and partly from the air tuyers placed radially around the circumference of the oxidation region. The biomass slowly moves down along with air passing through the series of thermo-chemical reactions in the reactor in order to convert into producer gas which leaves the reactor at the bottom through the grate.

The system has a provision for using a part of the heat of the producer gas for preheating the biomass. The producer gas, thus, passes from the bottom of the reactor to the annular region around the top of the reactor, through a duct. Since the raw gas leaves the gasifier at relatively high temperature (i.e. >573 K) [16,17], the

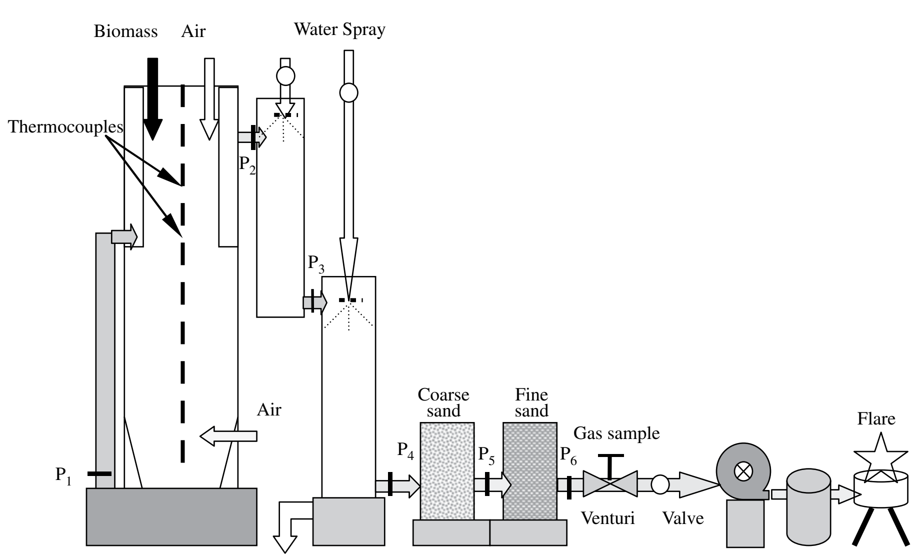

Fig. 1. Schematic diagram of the 75 kw_{th} downdraft (biomass) gasifier system.

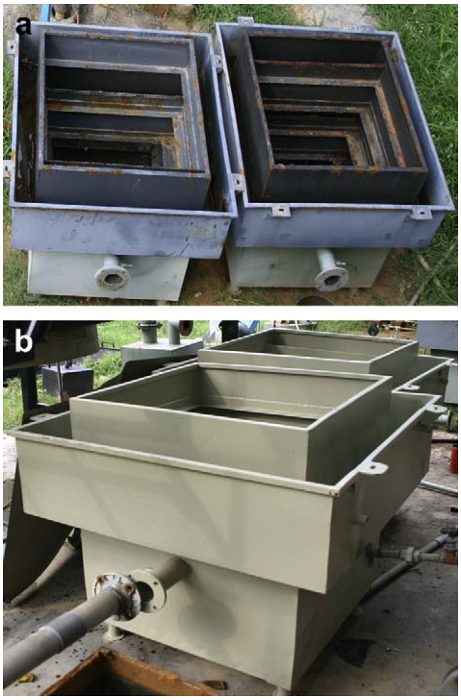

Plate 2. A view of sand bed filters. (a) Rusted and damaged filters. (b) New fabricated filters.

cooling of which improves not only the volumetric efficiency of engine but also helps in cleaning of gas. Parikh et al. [17] have reported that the design and volume content of cooling–cleaning system is an important aspect of the gasifier-engine system design. The tar laden gas cause erosion, corrosion and environmental problems in downstream equipment (Bridgewater [18]). Cooling of producer gas leaving the gasifier is carried out by the combination of two spray towers as shown in Fig. 1. The cooled producer gas is then allowed to pass through a coarse sand bed filter followed by fine sand bed filter in order to remove the moisture and tar content of the gas. The two-stage filtering ensures that the gas is cleaned to the desired level for use in the engines. Downstream of the fine filter, the gas has to the flare through the blower. Just before the flare, a water bubbler is installed in the path for safety reasons to avoid backfire. A venturimeter is installed in the path to measure the gas flow rate as shown in Fig. 1. Other details about the system are available in operating manual of the gasifier [19].

Plate 3. A view of charcoal filter with re-circulation tank.

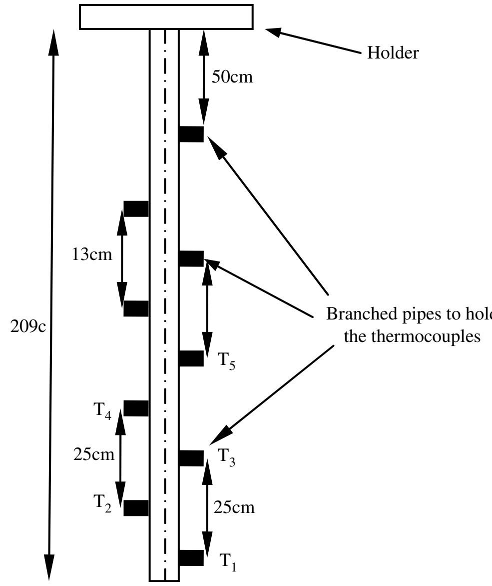

Fig. 2. Arrangement for temperature measurement inside the gasifier bed.

2.1. Preparation for experiments

When the present work was taken up, many parts of the above system were badly rusted due to poor maintenance since long. Thus, the work included fabrication of the coarse and fine sand bed filters, and the gasifier grate, while the charcoal filter and water re-circulation tank in the cooling system including pipeline were repaired/replaced. The sand bed filters were fabricated again using CRC sheets of 16 gauge available in the local market, after cutting into the required size were welded thrice to ensure leakage proof. The unit was then tested for leakage by sealing the unit at the bottom using water seal and subjecting it to air at a pressure of 80–100 mm WG with the help of a blower. The joints were examined carefully for leakage using a lit candle. It was then properly washed with acid to remove any stain or oil from the surface in order to get the surface powder coated. After spray of powder on whole surface, the filters are subjected to high temperature in an LPG fired furnace for 6–8 h. Subsequently, the filters were installed in the pipeline, then loaded with quartz of specified size and covered with the top cover. Fill the water seals of both sand bed filters with adequate water up to overflow level. The units were put to conduct leakage test. The pictorial views of old and new sand bed filters are shown in Plate 2(a) and (b).

The gasifier grate used to hold char particles was damaged due to long exposure to high temperature. Thus, the stainless steel grate was fabricated to withstand high temperature using special welding technique. The wooden board on which the manometer tubes were fitted has been replaced with new panel made of acrylic sheets and old plastic pipes were also replaced with new ones in order to avoid any kind of air leakage. The charcoal filter for treatment of cooling water before reuse also had to be replaced and recharged with fresh charcoal. A steel screen was fabricated and installed to avoid deposition of leaves and solid waste on the filter bed as shown in Plate 3. The water re-circulation line and the spray nozzles used in the cooling unit were replaced or repaired.

2.2. Measuring arrangements and instrumentation

Two arrangements were tried for measurement of temperature in the reactive, porous bed of the gasifier. The first arrangement had a structure made up of a long GI pipe with inclined branch pipes as

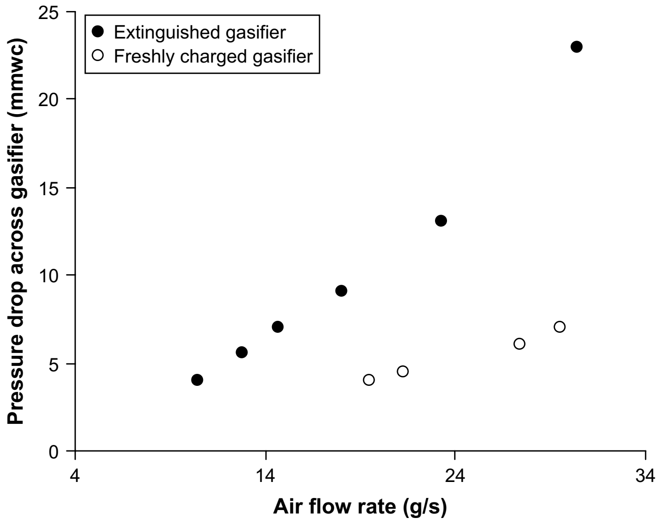

Fig. 3. Experimental data for pressure drop across the freshly charged gasifier and extinguished gasifier, cold flow.

shown in Fig. 2, to position the thermocouple beads at desired locations inside the reactor. Calibrated K-type (Chromel–alumel) thermocouples of length 220 cm (along with holder) were used for temperature measurement. Thermocouple wires were electrically separated from each other using ceramic beads. Two single-channel digital temperature indicators with a 12-channel selector switch were used to read out the temperature values at 16 different locations. The structure was suspended with the help of a holder from the open top before charging the gasifier. The thermocouples, thus, gave the fuel bed temperatures at different locations in the bed. Unfortunately, this arrangement could not be used for longer duration since it hindered the flow of feedstock. It was also observed that the GI pipes melted due to exposure at high temperature in the oxidation zone. In the second arrangement, therefore, three steel clad K-type thermocouples were used in all. First one, a 1.5 m long thermocouple was used to measure the temperature profile in the porous bed. This thermocouple was

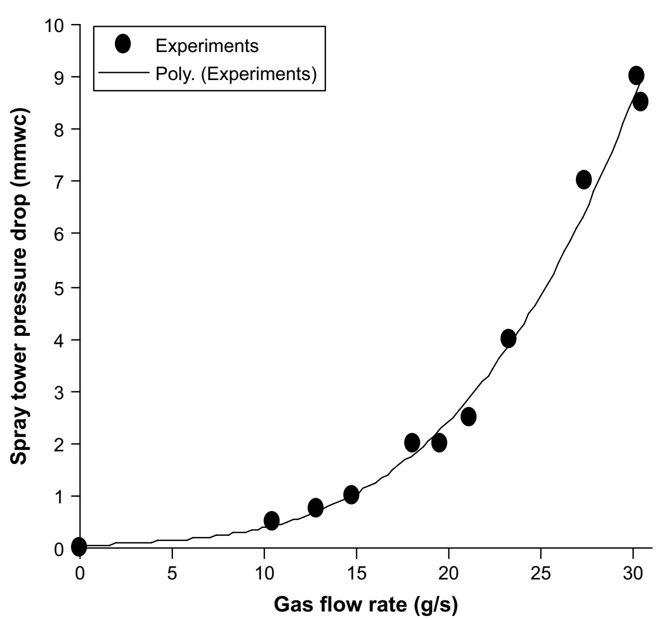

Fig. 4. Curve fit to the experimental data for gas flow rate versus pressure drop for spray towers in cooling unit.

inserted from the open top of the gasifier into the fuel bed to the desired position in the bed to measure the centerline temperature at different location above the tuyers. The second thermocouple was inserted through one of the tuyers in order to measure the temperature in the oxidation zone while the reduction zone temperature was measured with the help of the third thermocouple inserted into the reactor through the grate. The manufacturer's report of calibration of thermocouples is given in Appendix-A (A.1).

U-tube water manometers (least count of 1 mm) provided by the manufacturer is used to measure the pressure drop across the three main components in the system, viz., the gasifier, the spray tower and the sand bed filters. The tappings available at various locations for the purpose are shown as P_1–P_6 in Fig. 2. The flow rate of producer gas was measured using a venturimeter already provided in the system by the manufacturer. The venturi was placed in the path to the engine downstream of a straight pipe of diameter 3 in and length 26 cm corresponding to an L/D ratio of 6 to ensure fully developed flow upstream of the venturi. The pressure difference across the venturi tappings was obtained using an inclined tube (15° to the horizontal) water manometer, with a scale of least count 1 mm. In a venturi, the mass flow rate is proportional to the square root of the pressure difference across the venture inlet and the throat. The calibration for the venturimeter, as provided by the manufacturer is given in Appendix-A (A.2).

NUCON Gas Chromatograph, model no. 5765 was used to measure the composition of producer gas. The sample of gas at various gas flow rates was collected in air tight sampling bags after cleaning and cooling operation. The gas sample was injected into the column of GC with Argon as carrier gas. The detector was inserted into the gas stream at the end of the column, which records the time of the passage and the quantity of each component on a computer. The GC was calibrated using the calibrated producer gas sample of typical composition for CO: 19.2%, CH_4: 3.95%, CO_2: 11.57%, H_2: 20.45% and N_2: 45.1%. By comparing the areas of peaks for calibration gas and gas sample; the composition of gas sample was predicted by the computer software.

The moisture content of feedstock *Kiker* (Acacia) was measured following the procedure as recommended by ASTM D3172-73 (Grover et al. [20]). For this, three samples of biomass of known weight were subjected to a temperature of 110 °C in an electric oven for more than two and half hour. The weight loss in each particle was measured separately on weighing balance, which gives the moisture content of biomass feedstock which was found to be 11–13% on dry basis. The dry weight and volume of each particle gives the average density of the particle, in the present case, the average density of biomass was measured to be 894 kg/m^3. Other characteristics of feedstock have been obtained from the literature [20]. The *Kiker* wood cut on the chipping machine into cubical pieces of size 36 ± 4 mm was used as feedstock to charge the gasifier.

3. Experiments on gasifier in blower mode

The experiments were designed to obtain the fluid flow characteristics of gasifier, spray towers, sand bed filters and entire system as a whole in terms of flow rate in firing as well as in non-firing mode. The experiments are also conducted to obtain temperature profile in the reactive bed, the gas composition and calorific value in terms of air/gas flow rates. Non-firing mode represents the limiting case of zero biomass consumption (without any firing in a gasifier) with isothermal airflow at the ambient. For obtaining the pressure drop characteristics of porous gasifier bed in cold flow, the experiments are conducted for two types of gasifier bed arrangements; i.e. for freshly charged gasifier bed and for extinguished gasifier bed. In freshly charged gasifier bed, the bed is

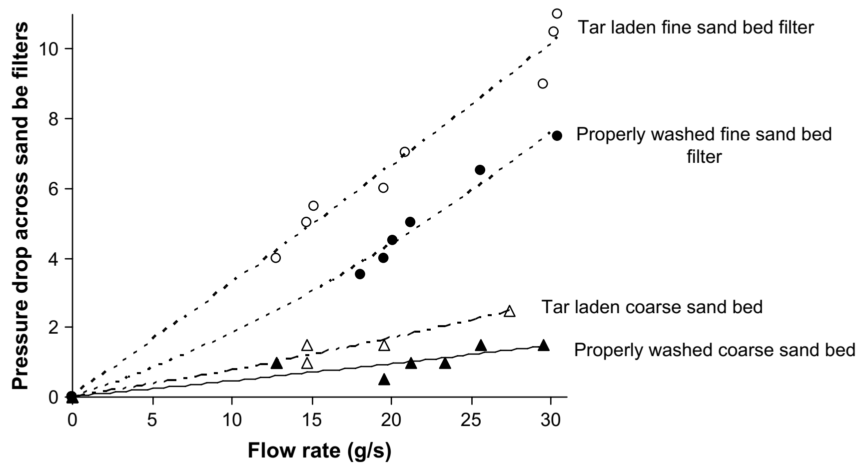

Fig. 5. Curve fit to the experimental data points for flow rate versus pressure drop across coarse and fine sand bed filters with tar laden and with properly washed quartz particles bed.

distributed uniformly with nearly same particle size throughout the bed, while in the extinguished gasifier bed the particle size is progressively decreases due to thermo-chemical reactions takes place when the gasifier was in operation earlier.

For start-up of the gasifier non-firing in freshly charged gasifier, the reactor was initially filled with charcoal particles up to air tuyers and the rest height was loaded with biomass particles of average size of 36 mm and the blower was switched on. The pressure drops at various tappings were recorded on manometers at different flow rates of air (obtained using venture). For second set of experiments which corresponds to firing mode, the gasifier was ignited, while the blower was on. As the temperature rises, the self-sustaining exothermic reactions take place. The gas released initially has very little of CO or H_2 and laden with tar. It was therefore, flared out to the burner. Measurements for pressure drops, temperature profiles and gas composition were started only after a steady, colourless flame was observed. In firing state, the particle size in gasifier bed starts decreasing progressively as the gasification reactions proceeds. The gasifier bed arrangement now in firing state is quite different from the freshly charged gasifier bed. The pressure drop across the hot gasifier bed, cooling–cleaning unit is measured at various flow rates. The typical time of 15–20 min was allowed after next increment in flow rate in order to subside the transients. The temperature in firing gasifier is obtained using the special arrangements as described in section Measuring arrangements and instrumentation, and gas composition is obtained at gas chromatograph. In order to highlight the influence of ash accumulation on pressure drop across the gasifier bed, the gasifier was run after shaking the grate properly for a longer period at given gas flow rates and readings were recorded. For third set of experiment, the gasifier was allowed to extinguish completely and experiments are conducted next day non-firing and with firing condition for this existing bed arrangement (i.e. progressively decreasing particle size distribution). Then the pressure drops at various tappings were recorded at various flow rates.

3.1. Experimental results and discussion

3.1.1. Fluid flow characteristics of gasifier system

The overall pressure drop across the system is a very important operating parameter and thus needs to be examined carefully when

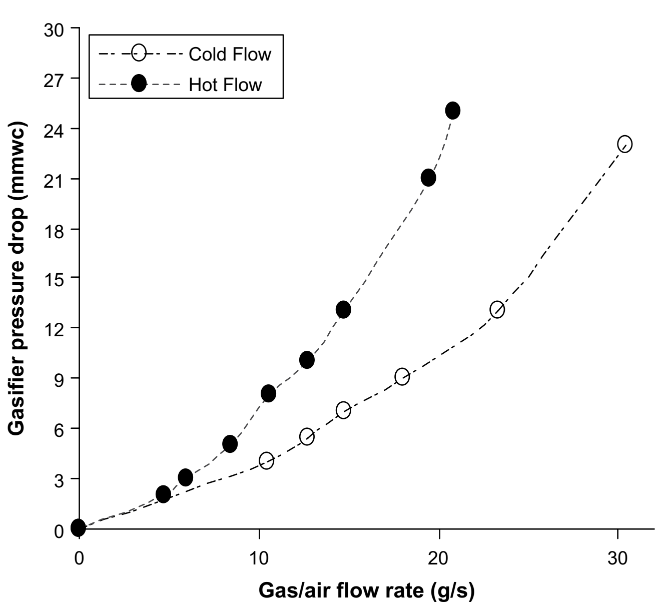

Fig. 6. Comparing the experimental results for gasifier pressure drop in firing and non-firing mode.

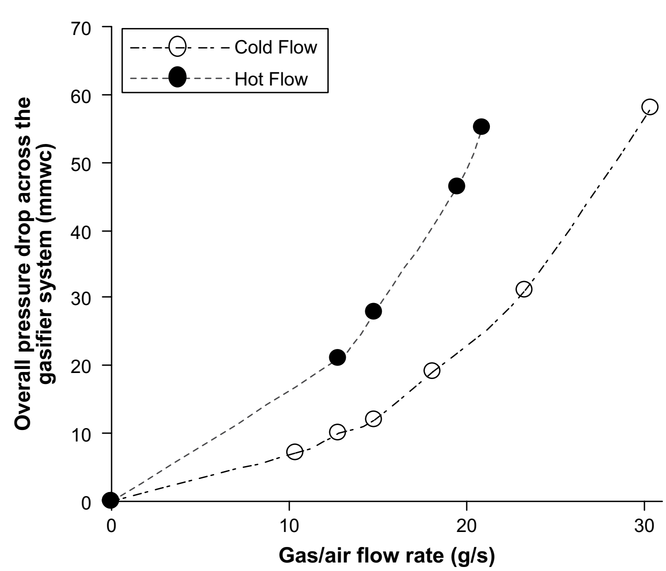

Fig. 7. Comparing the experimental results for overall pressure drop across the system (including cooling–cleaning unit) in firing and without firing state.

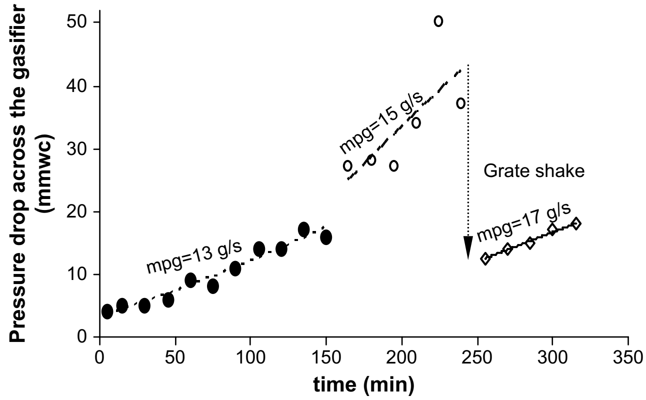

Fig. 8. Effect of gasification operational time on gasifier pressure drop bed and gas flow rates for gasifier in firing mode.

the objective is to couple a gasifier with an internal combustion engine. Therefore, the various sets of experiments were performed in cold flow (non-firing gasifier) as well as with firing to obtain the fluid flow characteristics of gasifier, spray towers, sand bed filters and entire system as a whole. Non-firing or in cold flow, for freshly charged gasifier bed, the gasifier was charged party with charcoal particles and partly with biomass particle of average diameter of 36 mm, while the extinguished gasifier constitutes of the particles in decreasing order similar to the case of fired gasifier as described earlier. The results for pressure drop versus flow rate in cold flow for both types of gasifier bed arrangements are compared in Fig. 3. As expected, the pressure drop for the extinguished gasifier bed is found to be much higher as compared to freshly charged gasifier bed, since the extinguished gasifier bed, the particle size progressive decreases, which offer much higher resistance to the flow, while freshly charged gasifier bed is constituted of uniform particle size distribution and constant bed porosity.

The cooling unit is made of two sections; both are co-current sprays. The spray is developed from an impinging jet, which mixes with gas and cools to the ambient and in the process removes some contaminants from the gas. Due to complexity of flow pattern of spray water and gas in the spray towers, their fluid flow characteristics have been obtained individually from measurements. Fig. 4 shows the pressure drop data for spray towers in the cooling unit for different mass flow rate of gas. It is also observed that the water

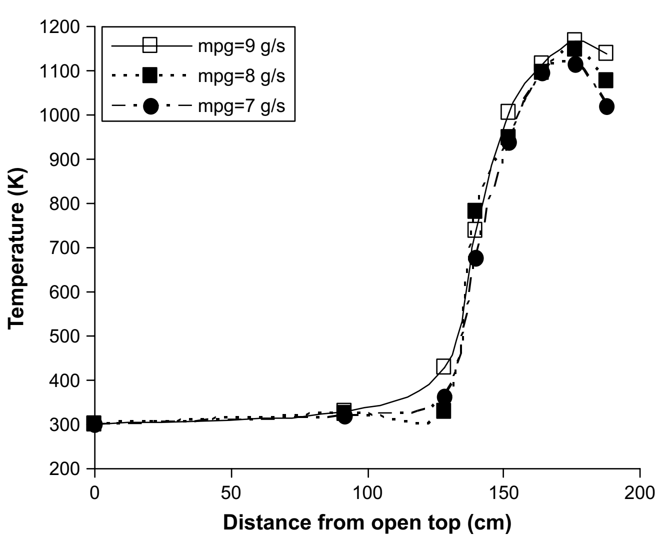

Fig. 9. Experimental temperature profile in the bed for different gas flow rate (m_{pg}), $d_b = 36$ mm, hardwood.

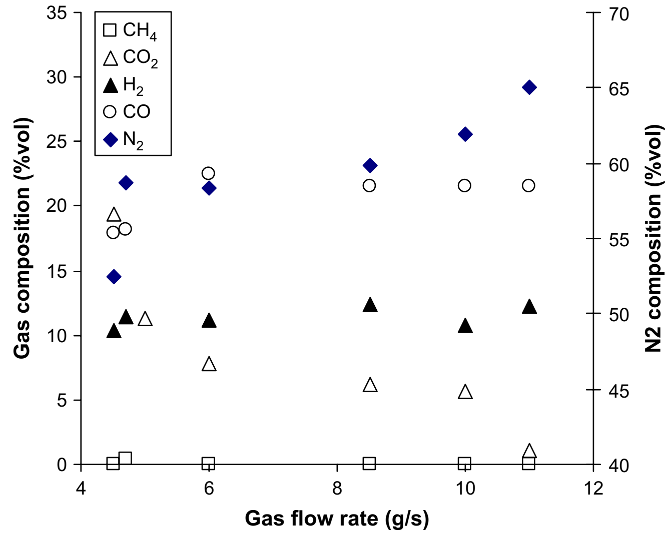

Fig. 10. Experimental results for CH_4, CO_2, H_2, CO and N_2 composition versus gas flow rate.

spray through impinging jet increases with increase in gas flow rate through the both spray coolers.

The sand bed filters are used to remove the tar along with other impurities. These are again comprised of two stages, the first being a coarse quartz filter, followed by a fine quartz filter. The course filters contains 1–2 mm sized quartz particles, while fine filter holding 200–600 μm sized quartz particles. Both filters have four-tier filtering arrangement with total filtering area of 1.2 m^2 with bed thickness of 85–90 mm.

The pressure drop across the coarse bed filter and fine bed filter is measured using U-tube manometer at different flow rates. In order to account for the effect of deposition of tar/particulates in the sand bed, the measurements are made with tar laden sand bed filters along with properly cleaned quartz bed (after removing the quartz particles from the sand bed filters and reloaded after proper washing and drying). The results for both coarse and fine sand bed filters along with and without the tar deposition on pressure drop at different gas flow rates are shown in Fig. 5. The pressure drop through the both filters is found to be a strong function of gas flow rate and quartz particle size. It is also observed that the case of tar laden filters shows higher pressure drop as compared to cleaned filters.

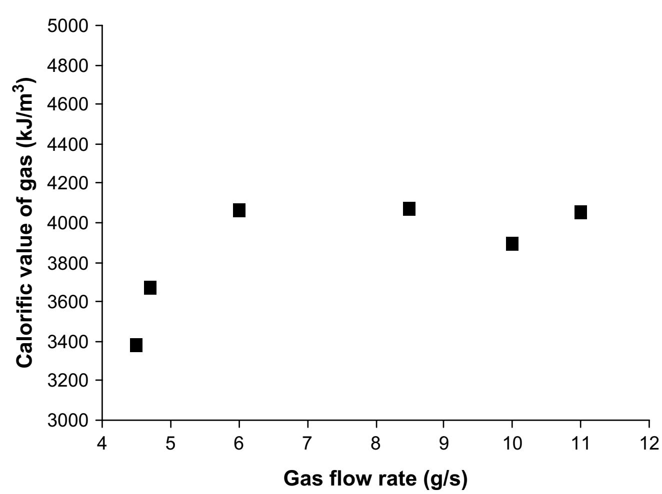

Fig. 11. Experimental results for calorific value of gas versus gas flow rate.

The experiments are conducted in hot flow to measure pressure drop and temperature profile in the bed, gas composition and calorific value of the gas. These experiments were conducted in the blower mode for pressure drop through the porous bed as a function of gas flow rate for average feedstock particle size of 36 mm. The experimental results for pressure drop through the porous gasifier bed in firing mode as a function of gas flow rates are plotted in Fig. 6. In order to demonstrate the influence of rising bed temperatures on pressure drop through the gasifier, the results of pressure drop for extinguished gasifier in non-firing mode are also included along with the results of firing gasifier as given in Fig. 6. It can be seen by comparing the results of same type of gasifier bed arrangement that the pressure drop across gasifier bed in firing mode gives much higher values as compared to non-firing extinguished gasifier bed. Similar trends are also observed for the case of overall pressure drop across the entire system in non-firing as well as in firing mode for different flow rates as shown in Fig. 7.

The pressure drop across the gasifier bed in hot flow state is indicator representing the health of a gasification system. Fig. 8 shows the result of pressure drop versus gasification time. It can be observed clearly that the pressure drop across the gasifier bed increases considerably with gasification time at different gas flow rates. As recommended in operational manual of the gasification system [19] that the pressure drops across the gasifier bed should not go beyond a prescribed value. For present case, at gas flow rate of 15 g/s, this prescribed limit is fixed at 40 mmwc. From the experimental observations, it can be observed that after nearly 250 min of operation, the pressure drop starts fluctuating near this critical limit. This situation of excessive pressure drop can be overcome by shaking the grate lever gently 3–4 times. It was observed that gasifier pressure drop reduces immediately to 12–13 mmwc and an increase in gas flow rate was also identified from 15 g/s to 17 g/s. Likewise, if we allow the gasifier operation for longer duration, further, the pressure drop again starts increasing and vice versa. The increase in the gasifier pressure drop with gasification time is expected, since the ash starts built up on the grate and offer much resistance to flow as gasification time proceeds and shaking of grate allows the removal of ash from the bottom of the gasifier bed.

From the experimental observation, the strong dependence of temperature, particle size distribution, gasification time and flow rates over pressure drop across the porous and reactive gasifier bed is established. The dependence of operational time on pressure drop through the sand bed filters is also established experimentally. The dependence of operational time is due to deposition of ash in the voids, while for sand bed filters it is due to deposition of tar/particulate matter in quartz constituting the filters bed.

3.1.2. Thermo-chemical characteristics of the system

3.1.2.1. Temperature profile. The temperatures at various locations in the reactive gasifier bed are measured to plot its profile for three consecutively increasing gas flow rates (i.e. 7, 8 and 9 g/s) as shown in Fig. 9. The experimentally obtained temperature profile is found to improve with increase in gas flow rate through the gasifier bed. The results also show the highest temperature is maintained near the tuyres (oxidation zone), as expected. The highest temperature in the bed improves from 1115 K to 1168 K for increasing the gas flow rate from 7 g/s to 9 g/s as observed from experiments' results.

3.1.2.2. Gas composition and calorific value. The gas sample is collected at gas venturi after cooling–cleaning operation (Fig. 1). The measured variation in composition of CO, CO_2, H_2 and N_2 at different gas flow rates are plotted in Fig. 10. Figure shows that CO and H_2 contents in product gas increase gently with increase in producer gas flow rate, while CO_2 shows decreasing trends with gas flow rate. The CH_4 content in product gas is observed to be very small in these experiments. The calorific value of the product gas can be obtained from the heating values of individual combustible component available in literature (Sridhar, [21]). The variation of calorific value of gas is plotted against the gas flow rate as shown in Fig. 11. which is find to be increasing for initial increase in gas flow rate, thereafter, it does not shows any significant variation with further increase in any gas flow rate. The average calorific value of gas for the present design (75 kW_{th} downdraft biomass gasifier) is observed to be 4150 kJ/m^3.

Increasing the gas flow rate improves the bed temperature profile leading to higher conversion of non-combustibles component (CO_2, H_2O) into combustible component (CO, H_2) in the product gas and thus the gas calorific value improves for increasing the gas flow rate from 4 g/s to 11 g/s as encountered in present work.

4. Conclusion

Experimental study on a 75 kW_{th}, downdraft (biomass) gasifier system has been carried out for obtaining temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling–cleaning train and across the system as a whole in both firing as well as non-firing mode. The issues related to re-fabrication of damaged components/parts are also discussed in order to avoid any kind of leakage. For non-firing gasifier, the extinguished bed (progressively decreasing particle size distribution) shows much higher pressure drop as compared to a freshly charged gasifier bed (uniformly distributed particle size). The pressure drop across the porous bed, cooling–cleaning train is found to be sensitive to the increase in flow rate. The pressure drop across the spray coolers is also found sensitive to the gas flow rate, while the sand bed filters is found to be a strong function of quartz particle size in addition to the flow rate through them. The tar/particulate deposited over the quartz particles constituting the filter bed gives comparatively higher pressure drop across them. The progressively decreasing particle size arrangement and higher operation time (more ash deposition in bed) is found to cause a marked increase in pressure drop through gasifier bed as well as through the entire system. Therefore, the shaking of grate is essential before a certain interval (i.e. ~250 min in present case).

In firing mode, the higher temperature in bed tends to better conversion of non-combustibles component (like CO_2, H_2O) into combustible component (like CO, H_2) in the resulting gas and, thus, improves in the calorific value of product gas. For progressively decreasing particle size distribution, and with increasing gas flow rates leads to more rise in bed temperature resulting much higher pressure drop across the bed. Any increase in temperature in bed either due to energetics of reactions or any other reason like increase in gas flow rates tends to higher resistance to flow through the porous bed and thus higher pressure drops.

The experimental data presented in this article may be useful for validation of computational codes for gasifiers. The pressure drop characteristics in terms of air/gas flow rate versus overall pressure drop may be useful towards the coupling of a gasifier to the gas engine for motive power generation or decentralized electrification applications.

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Appendix-A

Table A.1. Calibration report of thermocouple provided by manufacturer indicator-UNICAL 3001m, ambient temperature 33 °C.

S.No.	Source temperature (°C)	Instrument temperature (°C)
1	100	99.8
2	300	299.4
3	500	298.9
4	700	698.9
5	900	896.8

Table A.2. Calibration chart of venturi for gas flow measurement.

S.No	Calibrated venturi readings, x_1 (mmwc)	To be calibrated, x_2 (mmwc)	Mass flow rate of air in (g/s)
1	11	23	16.38
2	17	31	20.37
3	20	35	22.09
4	24	50	24.2
5	30	55	27.06
6	34	65	28.8
7	42	83	32.01
8	48	101	34.23
9	48	91	34.23
10	58	115	37.62
11	67	141	40.44
12	70	142	41.33
13	77	159	41.35
14	79	162	43.91
15	85	177	45.54
16	85	172	45.54
17	89	183	46.6
18	93	188	47.64
19	95	200	48.15
20	96	204	48.4

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